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Safeguarding the Crew and Engineering Systems for Human Missions

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Synthetic biology-definition

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- Synthetic biology is the area of biological research that combines science and engineering.
- Synthetic biology encompasses a variety of different approaches, methodologies and disciplines, and many different definitions exist.
- What they all have in common, however, is that they see synthetic biology as the design and construction of new biological functions and systems not found in nature.
  - Am I going to talk on the synthetic biology design and construction?
    - The answer is "NO".
  - But I will give few examples what NASA needs, gaps, expectations, and requirements might be, if and when we habitat human in other planets?

Safeguarding the Crew and Engineering Systems for Human Missions

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- Gap in technology for the human mission to space:
  - Microbial detection and their mitigation systems to facilitate spacecraft/habitation cleaning, sterilization, and maintenance will be paramount to prolong the longevity of human habitation on other planets.
  - Life-support processes (recycled resources, humidity, etc.) will promote the proliferation and colonization of microbes likely to play a role in subsequent bio-fouling/corrosion, and the pathogenesis of host organisms (e.g., crew members, plants).
  - In depth understanding whether spacecraft- and crew- associated microbiome can provide insight for a more efficient, lower cost, practical approach to specific challenges in space.
- Need:
  - Validated environmental monitoring systems and control strategies are crucial to
    1. preserve acceptable microbial burden levels in human compartments and life-support components,
    2. ensure negligible interference of false-positives with life-detection experiments, and
    3. prevent the inadvertent exposure of humans to extraterrestrial materials.

Planetary Protection Issues

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- PP policies derive from international treaties whose goal is:
  - "to preserve our ability to study other worlds as they exist in their natural states; to avoid contamination that would obscure our ability to find life elsewhere—if it exists; and to ensure that we take prudent precautions to protect Earth's biosphere in case it does."
  - Mandates are in place to minimize the likelihood of catastrophic outcomes as a result of human-associated cross-contamination between solar system bodies.
- To meet planetary protection obligations, NASA needs:
  - Integrated system technologies to protect human life from alien microorganisms (should they exist) and to shield engineering systems from bio-corrosion.
  - Assurance of compliance with evolving standards for planetary protection (both forward and backward contamination) relating to the human exploration of other celestial bodies.
  - A sound technical basis to determine whether the inadvertent shedding of bio-contaminants from human explorers can be minimized to such a degree that the search for life can continue in an unobstructed, meaningful manner.

Problem

Address Planetary Protection Policies for forward (Moon, Mars, Beyond) and back (Earth) contamination

Scenario-1

Planetary Protection	State of the art	Technology / Capability needs	Forward Contamination	Back Contamination	Deliverable
	Current PP requirements address only robotic missions to Mars (for human mission it is in conceptual stage).	Waste management, microbial dispersal (outside), cleanliness (inside), Microbial monitoring, Bio-barrier, Cleaning, Sterilization, Control	Moon (Cat I, II): Containing the dispersal of microbes and Mars (Category IV): countermeasures for microbial proliferation containment and control	Moon (no restriction) and Mars (Restricted entry): Sample receiving facility, Adapt MSR project technologies	TRL-9 technologies to meet the PP policies for MANNED MISSION TO MOON, MARS, AND BEYOND

NASA needs relative to microbial monitoring and control

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- NASA need an integrated microbial monitoring system, validated in a terrestrial Mars analog environment and ready for deployment on a human mission to Mars.
- Such a system is essential for human missions to comply with requirements to avoid harmful contamination and thereby facilitate the search for extraterrestrial life.
- Such system will bolster confidence in, and lend support to, PP efforts, hardware reliability, and sustained crew health.
- By forewarning human explorers of any significant fluctuations in microbial burden, such system allows the crew to take immediate actions to significantly diminish any threat to crew health, or deterioration of the habitation module resulting from bio-corrosion.
- Such system approach will strive to directly integrate the technologies with those being developed for robotic sample return missions, thereby providing a cradle-to-grave system-biology implementation capability for human exploration.

Microbial Monitoring

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- COSPAR recognizes that it is impossible to prevent some microbial contamination of pristine extraterrestrial environments once humans arrive. Neverthless, the policy stresses that every effort should be made to ensure that contamination be minimized, and in no instance should contamination be permitted in locations likely to harbor indigenous life. Current ground-based microbial monitoring technologies are insufficient to fulfill even “restricted Earth return” planetary protection requirements for robotic exploration.
- Synthetic Biology team should consider in developing the following:
  - Technologies to estimate the viable microbial burden, as such measurements will alert crew members of any inherent threat of microbial illness and will forewarn of any bio-deterioration of their habitat. Microbial monitoring techniques will also be invaluable in assessing the degree of microbial dispersal into the pristine environment under investigation.
  - An integrated, extensive sampling regime, an on-line/off-line monitoring system with an artificial intelligence–based feedback loop to interpret data, and plans for microbial mitigation and control to ensure sufficient longevity of flight hardware and an acceptable quality of life for the crew.
  - An understanding of the microbial diversity present in system fluids and system surfaces to foster the development of methods to mitigate and control microorganisms for bio-corrosion, bio-fouling, and human pathogenesis.

Microbial Monitoring System Characteristics

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- MMS should be:
  - an integrated engineering system from sampling to detection
  - validated in a terrestrial Mars analog environment
- MMS should estimate:
  - viable bioburden present within fluid, surface, and air samples from the simulated lunar and Mars habitats
  - the dispersal of microbes from human habitation
- MMS should be implemented and tested:
  - Lunar and Mars crewed flight activities

Problem
Controlling and monitoring microbial proliferation and its influence on the crew health and structural integrity of habitat systems

Scenario-2

Bio-corrosion, Bio-fouling, Bio-film

State of the art Ground-based solutions are available, no autonomous microbial monitoring and control system, LoCAD: measures dead and alive but not metabolically active microbes

Gaps identified
Differentiate dead and alive to measure metabolically active microbes, cleanliness for structural integrity, and medically important for crew health

Technology need
Mitigation technologies, Microbial monitoring technology (iMMS, MiDAS), LoCAD 2.0, Artificial intelligence for autonomous deployment

Scope
Mitigation of bio-corrosion/ bio-deterioration/bio-fouling issues, issues pertaining to the microbes-metal interaction, characterization of the microbial diversity

Deliverable
Flight proven (TRL-9) maintenance and microbial monitoring system

Controlling the Harmful Impact of

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- From the early stages of hardware development for future human exploration and prolonged human presence on the Moon and Mars, it is important to consider the deterioration of habitats due to the corrosive and fouling effects of human-associated microorganisms.
- Unlike robotic missions, human exploration activities will require life-support processes (recycled resources, humidity, etc.) that will drastically promote microbial proliferation, colonization, and subsequent bio-fouling/corrosion of hardware.
- Standards must be set (for permitted microbial load), and systems must be put in place to monitor and maintain the structural integrity of materials for long-duration human space exploration.
- Even though specific requirements/controls for these materials and structures are not currently known, in-flight cleaning and sterilization technologies will minimize maintenance costs and ensure crew health.
- At the very least, integrating controls and monitoring technologies to avoid microbial proliferation and subsequent contamination will be critical for science-related activities on the Moon and Mars.
- We should develop systems to monitor and prevent bio-corrosion/bio-film formation in water reservoirs, humidity/climate control, waste recycling, and other life-support components to avoid the catastrophic effects of deterioration.

Technologies Required to Control the Harmful Impact of Microbial Corrosion

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- NASA should mitigate microbial contamination and facilitate system cleaning, sterilization, and maintenance by:
  - Incorporating and adapting precision and semi-automated cleaning.
  - Developing sterilization technologies geared towards mitigating cyclic human re-contamination, including dry-heat (hardware), radiation (hardware and liquid), vapor hydrogen peroxide (hardware and open-air habitats), filtration (liquid and open-air habitats), wet-heat systems (liquid), and fumigation (open-air habitats).
  - Developing bio-barriers and other secondary human-derived contamination avoidance technologies to prevent bio-corrosion/bio-film formation and to maintain clean/sterile systems.

Controlling the Harmful Impact of Microbial Corrosion

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- Compile a comprehensive inventory of bio-corrosive microbial agents associated with human habitations.
  - Crew Microbiome, Environmetal Microbiome or Synthetic Microbiome?
- Develop and demonstrate the flight readiness of an artificial intelligence bio-corrosion microbial sensing system that can provide autonomous/semi-autonomous microbial contamination mitigation and control (system cleaning and sterilization).
  - Do we have risk-free Synthetic Microbiome?

Backup slides

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Session chair's wish list

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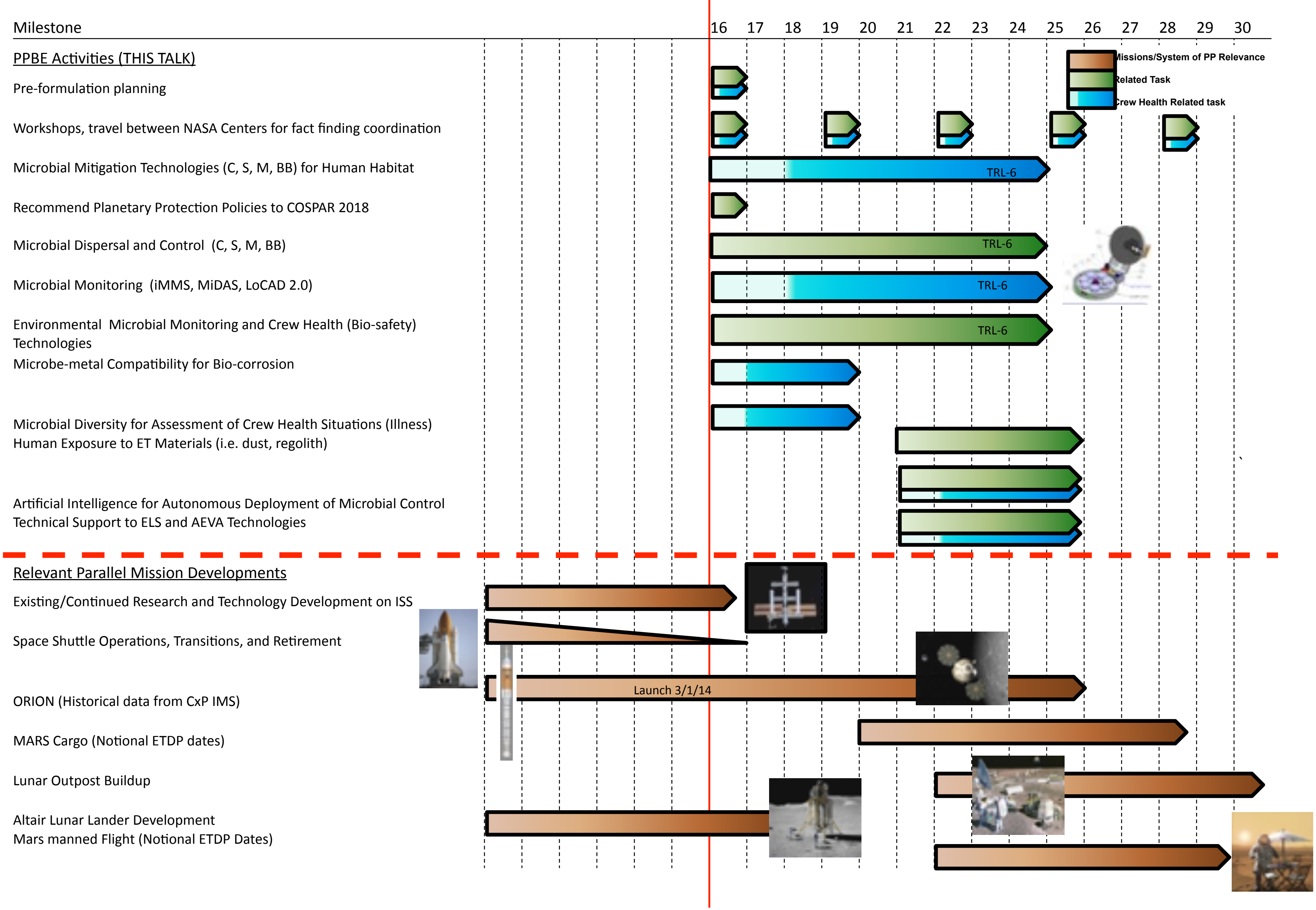
- Challenge the audience with some provocative thoughts
  - about both short and long term concerns, issues and views.
- Examples of concerns or implications of synthetic biology related to NASA's missions/activities
  - positive, negative, or uncertain
- Representative of the public issues we can expect to grapple with
  - ethical, theological, policy, legal, practical, evolutionary, or science/technology , financial etc
  - perhaps draw parallels with other technologies or deliberate human pursuits that have involved the intersection of life, science, evolution and technology?

Roadmap for Developing Planetary Protection and Bio-corrosion Technologies for Human Habitats

(includes schedule of mission/system development for PP-related systems to demonstrate integration)



C: cleaning, S: sterilization, M: monitoring, BB: bio-barrier